EFFECT OF PROCESS PARAMETERS OF ROTATIONAL ARC WELDING ON MECHANICAL PROPERTIES AND MICROSTRUCTURE OF DISSIMILAR ALLOY

SHORT SYNOPSIS

Submitted in partial fulfillment of the requirement of the degree of

DOCTOR OF PHILOSOPHY

by

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It is the work that is expected to be carried out under the supervision of **Dr. Prashant Bhardwaj** and co-supervision of **Dr. Husain Mehdi**.

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ABSTRACT

The effect of process parameters in rotational arc welding (RAW) on the mechanical properties and microstructure of dissimilar aluminium alloys is critical to achieving high-quality welds. This study investigates the influence of key parameters—such as rotational speed, welding current, arc voltage, and travel speed—on the mechanical and microstructural characteristics of two dissimilar aluminium alloys. The challenge of welding these alloys is due to their different chemical composition, thermal properties, and melting points which often lead to problem such as porosity, cracking, and poor mechanical performance in welded joints.

Experimental tests were conducted using different rotational speeds and heat inputs to evaluate their effect on tensile strength, hardness, elongation, and impact toughness. Micro structural characteristics of Fusion Zone (FZ), Heat Affected Zone (HAZ) and base material Performed using optical microscopy and scanning electron microscope (SEM). The results showed that higher rotation speed improved grain refinement in the FZ, resulting in improved hardness and tensile strength, but excessive speed caused the formation of defects such as hot cracking and cavities. Conversely, lower rotation rates resulted in coarser grain structures, reducing mechanical strength, especially in the heat - affected zones. This study also focused on the optimum combination of current and rotational speed considerably decreased defects in welding and also increased ductility and joint integrity. In contrast to the HAZ, which displayed progressive grain coarsening based on the heat input, the FZ had a fine equiaxed grain structure.

The development of intermetallic phases is influenced by variations in the metallurgical reactions of different alloys; this effect is particularly noticeable at high heat input and results in embrittlement.

This study offers important new information about how RAW process settings affect performance and mechanics. Welding micro structural characteristics of different aluminium alloys to allow for the best welding techniques prerequisites for enhancing performance in the automotive and aerospace sectors.

Keywords: Rotational Arc Welding, Fusion Zone, Heat Affected Zone, Aluminium Alloy

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1 Introduction

The process of welding owing to the distinct properties of materials, light metal alloys have presented both special opportunities and challenges. Due to their high strength-to-weight ratio, resistance to corrosion, as well as electrical and thermal conductivity, aluminum alloys, or Al-Alloys, are extensively used in the automotive, aerospace, and construction industries. Nonetheless, aluminium alloys can, for several reasons, be considered to be more complicated in the welding process than steels. The lower melting temperature of aluminium (approximately 660ºC) renders aluminium more prone to being deformed, burnt, or porous in the course of welding. [1] Because of its high thermal conductivity, which causes a loss of heat at a quick rate, a higher heat input is required to reach sufficient fusion. Oxide layer formed on the aluminium alloy which need to be removed because it has higher melting point than the base material which cause poor weld quality and also create disturbance during the welding. Aluminium alloy is difficult to weld so to attain satisfactory weld quality tungsten inert gas (TIG) and metal inert gas (MIG) should be used.

These process prevent excessive melting of the base material by controlling the excessive heat input [2, 3] in the welded region.To weld aluminum plate having larger thickness, pulse welding technique and advance welding method like friction stir welding should be employed. These techniques reduce cracking and distortion in the welding joints. Filler material also plays important role in weld quality so filler Material should also be chosen carefully. Commonly used filler material are ER4043 and ER5356 for aluminium alloy. During welding of aluminium alloy sometime hydrogen gas get trapped in the molten metal which create porosity in the welded joints[4]. Porosity is the common defect of the welding which can also weaken the structure rigidity. To minimize the gas absorption during welding, environment should be clean and weld pool should be covered by shielding gases like argon, helium etc. To remove the oxide layer and other impurities from the surface, welding region need to be clean by using chemicals or other method before welding to achieve high quality weld. On the basis of properties metal alloys are divided into different series and their weld ability is also different such as Al1XXX series is a pure form of aluminium having excellent corrosion resistance and conductivity, copper 2XXX series is highly durable and better application in aerospace sector, Mg 3XXX series

is durable as well as ductile in nature and mainly used for roof and cans. Silicon -based 4xxx series is suitable for welding. The 5xxx series, which contains magnesium, is corrosion resistant and is often used in marine applications. The versatile 6xxx series with magnesium silicon is widely used in the construction and automotive industries.

The high-strength 7xxx series features zinc, critical for aerospace, while the 8xxx series has professional applications. Each series exhibits different solder ability and requires different techniques and Precautions during welding. For example, 6xxx series alloys are easier to weld but require post-weld heat treatment to restore strength, the 2xxx series, however, are more prone to thermal cracking and require specialized welding procedures.

2 Literature Review

2.1 Rotating Arc welding

Rotating arc welding (RAW) is an advanced variation of conventional arc welding techniques, used to improve weld quality through a unique rotational motion of the arc during the joining process revealed in Fig. 1. This rotation allows for enhanced control over the heat input and distribution, leading to better weld properties such as uniform bead geometry, reduced defects, and improved mechanical characteristics in the weld and heat-affected zones (HAZ) [5, 6]. For instance, ER4043 and ER5356 are popular filler wires for Al-alloys, chosen for their suitability to produce sound welds with little cracking.

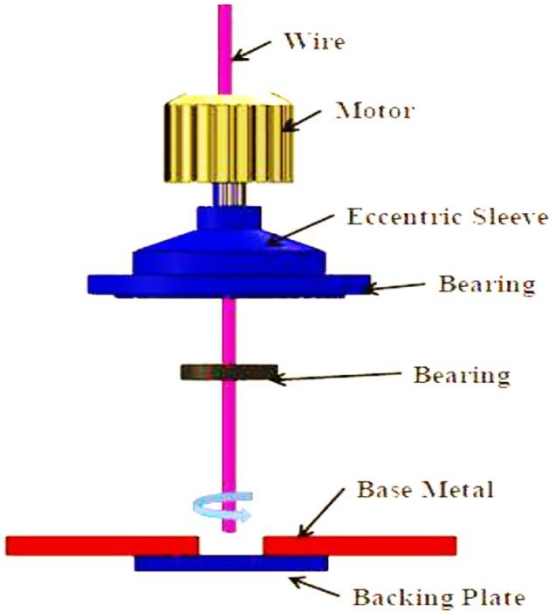

Figure 1: Schematic setup of rotating arc welding

One of the key challenges in welding aluminium is the tendency for porosity to form in the weld due to hydrogen absorption. Commonly used welding technique in industry is arc welding which provide precision and better control of heat flow in welding joints. Its major application can be seen in aerospace and automotive industry. Rotating arc welding is advancement in arc welding which can give better results as TIG, MIG and other fusion welding. Conventional arc welding creates irregular heat distribution, inadequate fusion and distort the micro structure of the base material. By adding arc rotational these issues can be minimized and better weld quality with improved micro structure could be achieved.

2.2 Working Principle of Rotating Arc Welding

The key distinction in rotating arc welding lies in the movement of the welding arc. In traditional arc welding, the arc is stationary in relation to the motion of the welding electrode or torch. But in rotating arc welding, the arc is manually or electronically controlled to oscillate or rotate in a circular, elliptical, or spiral movement as it moves along the path of the weld. The rotation of the arc may be caused by rotating the torch, employing specially designed nozzles, or using high-tech control circuits that rotate the current in such a manner that causes the arc to rotate. There are various methods of implementing arc rotation

• **Mechanical rotation**: The electrode holder or welding torch is rotated physically along the axis of the arc. The rotation is either continuous or oscillating based on the requirement. The motion of the torch is coordinated with the welding action to provide evenness and accuracy.

•**Magnetic field-induced rotation:** A controlled magnetic field is applied to the electrode, causing the arc to rotate due to the Lorentz force acting on the charged particles in the arc plasma. This method provides more precise control of the arc rotation and is often used in automated systems.

•**Electronic modulation:** Modern welding power sources can be programmed to modulate the current in a way that causes the arc to oscillate in a defined pattern. This method is highly adaptable and can be integrated with computerized welding systems for automated operations.

By rotating the arc, the heat input into the weld pool is distributed more evenly, which helps to minimize localized overheating and thermal distortion. The rotating arc also improves the stirring action within the molten metal, enhancing fusion between the base material and filler material.

- **HAZ Control**

One of the critical aspects of any welding process is managing the HAZ, which is the region adjacent to the weld metal that undergoes micro structural changes due to the heat of the welding process. Under conventional arc welding, HAZ has the possibility to experience high cooling and heating rates along with unwanted microstructures such as coarse grains, brittle phases, or excess residual stresses.Such changes may reduce the mechanical properties of the weld as well as surrounding base material, particularly in high-performance use where toughness, ductility, and resistance to fatigue are required [12].By regulating the heat input of rotary arc welding, these issues can be avoided.

By lowering the maximum temperature at all locations and permitting a more progressive heat cycle, the arcs revolving motion disperses the heat over a greater area.

By forming a smaller grain size and enhancing mechanical properties, this tends to improve the microstructure at HAZ. For instance, poor microstructure, i.e., the development of martensitic (CGHAZ), is decreased with an increase in hardness and susceptibility. The ability to work with HAZ is critical when welding high-performance alloys like P91 or P92 steel, which are widely employed in the petrochemical and power generation industries. Because they have very high temperature sensitivity, these materials can be welded via the rotary arc welding process without losing their microstructure.

2.2.1 Benefits of Rotating Arc Welding

Benefits of rotating arc welding compared to conventional arc welding are follows

1. In the normal arc welding, heat is concentrated in a small arc area that rapidly cools or heats up during the finish process, causing stress, overheating, and part distortion.Heat is dissipated during rotating arc welding, which 6 reduces the weld pool temperature.Due to reduced penetration, weld beads widen and profiles improve.

2. Rotating arc welding decreases the possibility of common weld defects like undercut, porosity, and lack of fusion.The base and filler components will bond better in the weld when the melted metal gets agitated more intensively.
3. The microstructure of the weld and heat-affected zone is probably going to be improved by rotating arc welding. This technique reduces brittle structures that are inherently susceptible to thermal cycles and refines grains by controlling the pace of heat and cooling.
4. A smoother and more consistent weld bead is produced by the arc's rotating motion when there are fewer surface imperfections.
5. Welds with superior mechanical qualities can control microstructure and heat input. Rotating arc welding creates welds with superior toughness, ductility, and fatigue resistance in contrast to traditional arc welding.
6. Carbon steels (such as AISI 1020), stainless steels, aluminium etc. and materials that are difficult to weld materials like high-strength low-alloy steels and nickel-based alloys can all be joined together with rotating arc welding.
7. Rotating arc welding is perfect for high-volume production settings where uniformity and repeatability are crucial as it is simple to incorporate into automated welding systems.
8. The equal distribution of heat minimizes the temperature in the weld and HAZ, leading to reduce the levels of residual stress. As high residual stresses may result in defect like fracture, deformation or short fatigue life etc.

2.2.2 Rotating Arc Welding Process Parameters

Like all welding processes, the success of rotating arc welding depends on careful control of several key parameters:

- **Arc Rotation Speed:** The speed at which the arc rotates is one of the most critical factors in determining the heat input and weld bead shape. Faster rotation speeds spread the heat over a wider area, reducing peak temperatures but also reducing penetration. Slower rotation speeds concentrate the heat in a smaller area, increasing penetration but also the risk of localized overheating.
- **Welding Current and Voltage:** The current and voltage used in rotating arc welding have a direct impact on the arc's stability and the overall heat input. Higher

currents and voltages increase the heat input, while lower settings reduce it. The combination of current, voltage, and arc rotation speed must be carefully balanced to achieve the desired weld quality.

- **Travel Speed:** The speed at which the welding torch or work piece moves relative to the arc also affects the heat input and weld bead shape. Faster travel speeds reduce the amount of heat input and result in narrower weld beads, while slower travel speeds increase heat input and result in wider weld beads.

- **Filler Material:** The choice of filler material is important in rotating arc welding, as it must be compatible with the base material and provide the necessary mechanical properties. Common filler materials include ER70S-6 for carbon steels like AISI 1020, as well as stainless steel and nickel-based alloys for more demanding applications.

- **Shielding Gas:** Proper shielding gas selection is important to protect the weld pool from contamination by atmospheric gases such as oxygen and nitrogen. Argon, helium, or mixtures of these gases are commonly used in rotating arc welding, with the choice depending on the material being welded and the desired weld characteristics.

3 Research Objective

- To develop a mathematical model to study the optimization of process parameters of the rotating arc welded joints of dissimilar Al-alloys

- To study metallographic characterization of rotating arc welded joint using optical microscopic and SEM, EDS, and XRD.

- To study mechanical properties of rotating arc welded joints such as micro-hardness, tensile behavior and residual stress.

- To study the effect of various process parameters of the rotating arc welding on the weldments.

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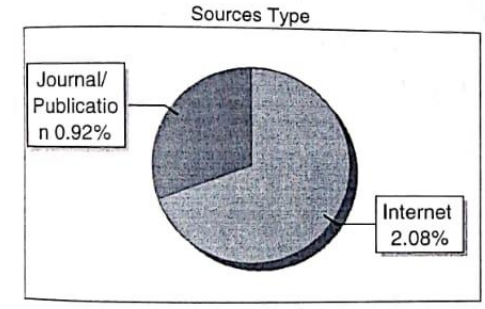

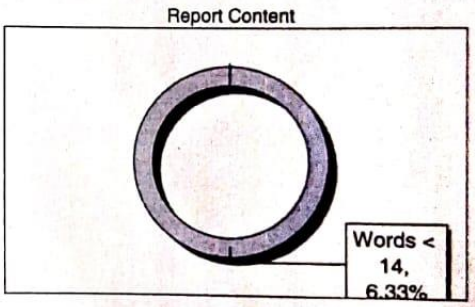

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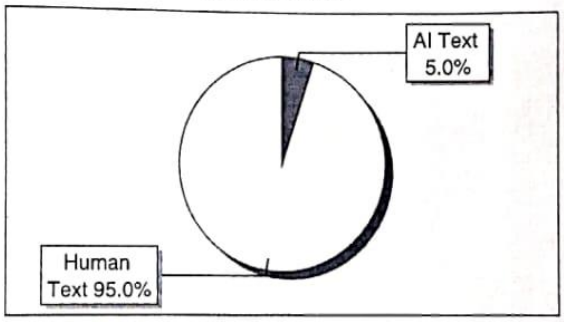

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